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Hydro, tidal and wave energy in Australia

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Abstract

The three renewable energy technologies discussed in this paper are based on water, but differ markedly in terms of the size of the available potential resource, the maturity of the associated conversion technologies, the extent to which they have been exploited to date, and the current research effort being devoted to their future development. Hydro-electricity and tidal power are both very mature technologies. The exploitation of Australia's relatively limited potential for hydro-electric development began over a century ago and the opportunities for further hydro-electric development are now very restricted. The country's significant tidal power resources, on the other hand, have not been exploited for electricity generation to date, but continual assessment of the feasibility of tidal power projects has been undertaken over the past half century. Although Australia has large ocean wave energy resources, ocean wave energy conversion technology is not yet fully commercial and no commercial wave generation plants are operating in Australia. A small number of wave energy conversion devices, however, are at the pilot testing stage.

1. Hydro-electric power

Australia has few large rivers, low topographical relief and low rainfall. Relative to many other continents, the natural potential for hydro-electricity development in Australia is therefore limited. Large hydro-electric schemes nonetheless provide the vast majority of the electricity currently generated from renewable energy sources in Australia. Total installed hydro-electric generation capacity is 7577 MW, with a total average annual long-term hydroelectric output (ALTHEO) of 14,568 GWh, which represents approximately 7% of electricity supplied into main grids in 2003/04 [1].

The greatest hydro potential occurs in sites located in the island state of Tasmania and the two south-eastern states of the Australian mainland, New South Wales and Victoria. Together, these three states account for over 91% of installed generation capacity. Most of the installed capacity in NSW and Victoria forms part of the Snowy Mountains Hydro-Electric Scheme (table 1).

Table 1. Installed hydro-electric generation capacity in Australia by state.

	Installed generation capacity (MW)
Snowy Mountain Hydro-Electric Authority Scheme	3756
Hydro Tasmania	2262
Queensland	639
New South Wales	392
Victoria	503
Western Australia	32

The other state with significant capacity, Queensland, has two hydro-electric schemes in the far north of the state with a combined generation capacity of 139 MW as well as a 500 MW thermal pumped storage hydro-electric facility connected to the Brisbane’s main water supply reservoir in the south of the state.

The largest hydro-electric scheme in Western Australia is a 30 MW hydro-electric plant that was retrofitted into the Ord River Irrigation scheme in the far north of Western Australia in 1997. There are also two small hydro-electric schemes in the south of the state. One of these, the 2 MW Wellington Dam hydro-power plant on the Collie River, was damaged by floods in the late 1990s and is unlikely to be brought back into service. The other is a small 100 kW scheme on the Pemberton River that was recently restored as cultural heritage restoration project.

There are no hydro-electric schemes in either the Northern Territory or South Australia, although the option of using South Australia’s water supply systems as pumped storage to provide peak power has been investigated in the past.

Tasmania

Australia’s island state, Tasmania, is the country’s smallest, most southerly and most mountainous state. Although the state has only 30% of Australia’s installed hydro-electric generation capacity, the state-owned generator, Hydro Tasmania, produced 9,610 GWh of electricity from its 27 hydro-electric power stations in 2004/05 [2], representing almost 90%

of the total electricity generated in the state and approximately 66% of Australia's hydroelectric generation output for that year.

The first hydro-electric schemes in Tasmania were small and built by mining companies in remote areas in the late 19th century, while the first municipal hydro-electric scheme constructed in the Southern Hemisphere was a 1 MW plant constructed on the South Esk River in 1885 [3]. Hydro-electric construction in the state began in earnest with the failure of a private venture attempting to construct a large scheme at the Great Lakes to generate electricity for zinc smelting. This led the state to establish a hydro-electric department to take over responsibility for the construction of hydro-electric schemes in 1914 [4]. This produced a policy of hydro-industrialization, a rolling hydro-electric scheme construction program used to underpin the state's industrial development. The program was accelerated in the aftermath of the Second World War and included schemes of increasing scale (figure 1), which from the 1960s onward, increasingly encroached into pristine wilderness areas, sparking significant public opposition [5]. Australia's modern environmental movement evolved from the political controversy, which spilled over into the national and international arenas. This culminated in a High Court decision in July 1983 that upheld the Australian Government's constitutional power as a signatory to an international environmental convention to halt construction of a proposed scheme that would have inundated the Franklin River in the south-west of the state [6]. The last large hydro-electric schemes in the Tasmania were completed in the mid-1990s and with no further opportunities for hydro-electric schemes the state-owned generator began to concentrate on wind power generation opportunities.

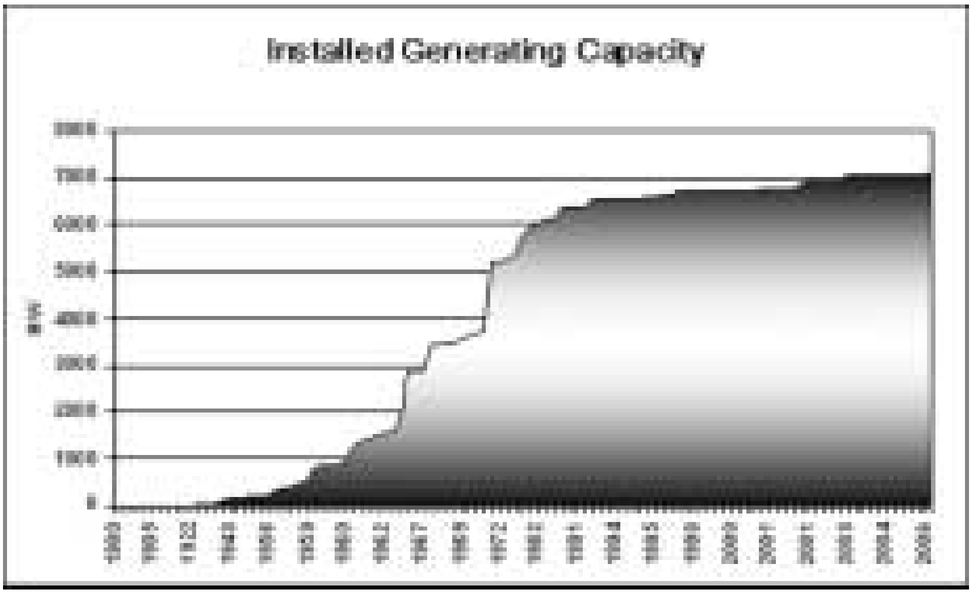

Figure 1. Cumulative installed hydro-electric generation capacity in Tasmania, 1900–2006.

Snowy Mountains scheme

The other major hydro-electric scheme in Australia, the Snowy Mountains Scheme, diverts the Murray, Murrumbidgee, Snowy and Tumut Rivers in the Blue Mountains. Jointly owned by the Commonwealth, the New South Wales and Victorian Governments, the scheme was constructed in the post-Second World War period and completed in 1974. It was the iconic national development and engineering project of the era, consisting of seven major power stations, 16 major dams and over 200 km of tunnels and aqueducts, most of which are located in New South Wales. The scheme’s total output in 2005 was 4385 GWh, representing 30% of Australia’s hydro-electric generation output for the year [7].

Potential for future expansion

All viable sites for large hydro-electric schemes in Australia have either been fully developed or are located in protected areas. The largest proposed hydro-electric project currently being investigated is a 50–80 MW scheme on the Burdekin River in northern Queensland. Opportunities exist, however, to increase the output from most of the existing large hydro schemes through refurbishment. Hydro-Tasmania, for example, estimated in the late 1990s that turbine runner upgrades could increase output by 1 to 4% for a significant proportion of its existing capacity and by about 10% for a small proportion of capacity [8]. The option of refurbishing the Ord River scheme in Western Australia to increase output by approximately 5% is also being assessed and similar improvements are likely to be possible from large hydro-electric schemes in the other states.

There is also some scope for expanding hydro-electric output by constructing smaller hydroelectric schemes, although potential is limited. According to the Australian Greenhouse Office, 41 small hydro-electric projects with a total generating capacity of over 358 MW are being taken forward [9]. Most of these are located in areas with existing hydroelectricity infrastructure. The total combined potential for small hydro-electric generation in NSW has been estimated to be 62 MW from 36 existing sites [10]. In Victoria, the potential to retrofit 16.5 MW of hydro-electric generation capacity to existing water supply infrastructure has been identified and six of these are currently in the process of being installed on the state’s water supply system [11]. One company in Australia, Tamar Designs, manufactures a wide range of small hydro-electric turbines and sells into the Australian and regional markets. The only research undertaken by the company is trial and error testing of new turbine blade designs.

At the mini (<1 MW) and micro (< 0.1 MW) scale, many farms and individuals in remote and regional areas, where connection to the grid is either not an option or is costly, have constructed mini or micro-hydro systems, although the actual extent to which these are used is difficult to gauge as the construction of these systems is not well documented. Typically, the systems are around 5 kW with a capital cost, excluding civil works, of approximately AUS$10,000 [10]. Capital and maintenance costs are reported to compare favourably with the costs of the alternative, connection to and purchasing electricity from the grid. These micro systems can be utilized, however, in a relatively limited number of locations in Australia [12]. Two Australian companies, Platypus Power Ltd and the Rainbow Power Company, manufacture micro hydro turbines. The latter company has decided to cease production due to the costs of testing its micro-turbines to demonstrate compliance with new radio frequency interference regulations. Given the low volume micro-hydro turbine market, the company intends to supply imported micro-turbines.

2. Tidal power

The energy available from tides is approximately proportional to the square of the tidal range, making the extraction of energy from the tides practical at only those sites that have both very large tidal ranges and landforms suitable for tidal plant construction. Such sites are not commonplace, only 26 being listed by the World Energy Council report [13].

Nearly all of Australia's potentially exploitable tidal energy is located in the Kimberley region in the north-west of Western Australia, where tidal ranges vary from 7 to 12 m (figure 2) and the coastline comprises steep cliffs and deep bays and inlets.

The existence of large tidal ranges in this region is a consequence of resonance in the Timor Sea. This has been long known [14] and interest in using these resources to generate electricity dates back to at least the middle of the last century [15]. Construction of the La Rance tidal power scheme in France and the Murmansk scheme in north-west Russia caused more serious attention to be focused on these resources. A preliminary engineering study estimated the total tidal power resources in the Kimberley region to be approximately 3000 MW [16]. The study, which was coloured by an engineering optimism characteristic of the era, proposed 'atomic blasting' of the sea cliff faces to close off whole basins and dismissed the problems associated with generating large amounts of electricity in such a remote location by assuming that the electricity could be used either to develop the area's rich mineral and agricultural potential or supply the growing demand for electricity in the capital city, Perth, 1931 km to the south. This optimism was no doubt buoyed by the contemporary construction of the huge Snowy Mountains Hydro-Electric Scheme as a national engineering project. The study led the Western Australian Department of Works to commission a French consulting firm that had worked on the design and construction of the La Rance project to undertake a more detailed assessment of the potential for tidal power in the Kimberley region.

The investigation focused on a proposed 570 MW tidal power station with pumped storage capacity and a net output of 170 MW at Collier Bay north of Derby. It found that the neap tides were too small for power generation and that many of the estuaries had soft, silty bases, which would make civil engineering works costly. The remoteness of the region was also considered a problem, but the report concluded that the proposal would not be economic even if a load for the electricity could be found [17]. Dr Edward Teller subsequently visited the region to investigate the potential for using 'nuclear dynamite' in local mining and civil

Figure 2. Mean annual tidal ranges in Australian coastal locations (adapted from Australian Bureau of Meteorology data)

engineering works, including the atomic blasting of sea cliffs at Cape Keraudren south of Broome to construct tidal power schemes [18].

The oil price rise of 1973 led the State Energy Commission of Western Australia (SECWA) to reassess, again, the potential for tidal power in the region. This was driven in part by the fact that the state lacked the coal deposits or hydro-electric resources of its rival eastern states, leading SECWA to feel ‘a special responsibility’ for developing Australia’s tidal resources [19]. SECWA used the pumped storage model in Collier Bay, with 170 MW firm and 570 MW peak output, but based on a floating caisson system as used in the pilot plant at Murmansk in Russia. The study again confirmed that the project was uneconomic [20]. In

1991, a Western Australian Legislative Assembly Select Committee recommended that the Kimberley region's tidal resources be reinvestigated [21]. The subsequent study considered that the problems associated with the remoteness of the King Sound and Collier Bay options near Derby could be overcome using battery storage or the production of hydrogen for use in thermal backup, but dismissed the sites due to the inhospitable conditions, the lack of available rock for dam construction and the high sedimentation rates [22]. The study instead recommended a 20 MW demonstration project at Cape Keraudren, despite the site's lower tidal range, due to its closer proximity to the Pilbara interconnected grid and mining loads. A private company, Derby Hydro Power Ltd, was formed to further develop the proposal.

In mid-2002, Western Power was forced to call tenders again for the supply of electricity across the west Kimberley following the collapse of its agreement with the LNG consortium. Tidal Energy Australia Ltd prepared a modified, lower cost tidal power proposal [24]. The Environmental Protection Authority of WA expressed severe reservations about the potential impact of the project on the ecology of the Doctor's Creek area [25], but the economics of the proposal, estimated to cost \$360 million, were improved by a \$75 million contribution from the Commonwealth and the availability of Renewable Energy Certificates. Tidal Energy Australia, however, withdrew from the tender when informed by engineering consultants that additional dredging would be required that would greatly increase the estimated civil construction costs.

Tidal Energy Australia modified the design once again and advocated using the electricity to supply a proposed zinc processing operation in the area, while politicians that supported the project argued for using the electricity to produce hydrogen and piping this to Perth. The market for the former option has not materialized to date, while the market for the latter option was never clear.

Little other serious investigation of harnessing tidal power or tidal flows to generate electricity has been undertaken in Australia. In the late 1990s, the Northern Territory Power and Water Authority examined the prospects for harnessing tidal currents in Darwin Harbour [8] and undertook testing of an axial tidal turbine in the Apsley Strait between Bathurst and Melville Islands in conjunction with the Northern Territory University [26].

The Bass Strait islands between mainland Australia and Tasmania have tidal currents in the range of 100–140 W/m2 and tidal power was one option considered for supplying electricity for these islands. However, these islands also have some of the best wind resources in the world and not surprisingly, these were selected as the most promising alternative to diesel.

Despite the small tidal ranges occurring along Australia's southern coastline, there has been some interest in identifying potential sites in Victoria [27].

3. Wave power

The wave power potential is related to the distribution of winds, and the strongest winds occur between latitudes 40° and 60° in both hemispheres, with wind strength steadily decreasing toward the equator and the poles. The highest concentrations of wave energy in these main wind belts occur on the downward ends of the fetches, which are on the eastern sides of the oceans [28]. In these locations, which include the southern and western coast of Australia, the power in wave fronts varies from 30 to 70 kW/m, with peaks of 100 kW/m [29].

The greatest wave energy resource in Australia is therefore located along its southern coastline from the southwest of Western Australia to the southern coastline of Victoria and on the west coast of Tasmania, where the average inshore wave energy densities range up to 84 kW per metre of crest width [30]. As any site with an average wave power level of over 15 kW per metre has the potential to generate wave energy at competitive prices, many other coastal areas in Australia have potentially commercial wave energy resources (figure 3).

The prospects for using these wave energy resources to generate electricity have been investigated since the late 1970s [31,32]. The technology for using tidal energy resources is, however, still at the R&D stage and no commercial wave energy generation plants have been constructed in Australia to date. Nevertheless, interest in designing and deploying costefficient wave generation devices increased in Australia during the 1990s and two Australian companies have been actively involved in the research and development and pilot testing of wave energy conversion technologies.

Energetech Australia Pty Ltd, in conjunction with university-based research teams, has developed and tested a prototype model of a Wave Energy System, an oscillating water column (OWC) generator that uses about 40 m of coastline and a parabolic wall to focus the wave energy into the column. This results in an approximate three-fold amplification of the rise and fall of the incoming wave, enabling significant power to be generated from even relatively gentle (approx. 1 m) swells. The incorporation of a two-way Denniss-Auld turbine with low rotational speed and high torque increases both the efficiency and reliability of the wave generator and makes it suitable for coastal situations where there is a deep-water harbour breakwater, or where rocky headlands/cliffs occur.

In 2000, Energetech and its joint venture commercial partner, Primergy, received a $750,000 grant to develop a 300 kW wave generator based on the OWC prototype at Port Kembla in New South Wales. Full-scale ocean trials began in October 2005. A portion of the power generated is used to desalinate water on-board the plant. The results from trials to date indicate that the plant's output is 20% higher than the earlier research predicted and it produces 321 kW in two-metre waves with seven second periods (figure 4). The plant is expected to produce over 500 MWh of energy or approximately 1100 million litres of water per year. The company's ongoing R&D program is aimed at improving the efficiency, functionality and cost-effectiveness of its wave energy technology. The results from a number of specific R&D areas are synthesized using system models and improvements are integrated into the design program [33].

A second company, Seapower Pacific, has developed the CETO wave generator, named after a sea monster in Greek mythology and an acronym for Cylindrical Energy Transfer Oscillator. This unit differs from most other wave energy conversion technologies in two important ways. It is the first wave energy converter design permanently anchored to the sea floor, providing greater protection from storm damage. Secondly, the device uses wave energy to compress a submerged diaphragm to pressurize the water and pump water ashore.

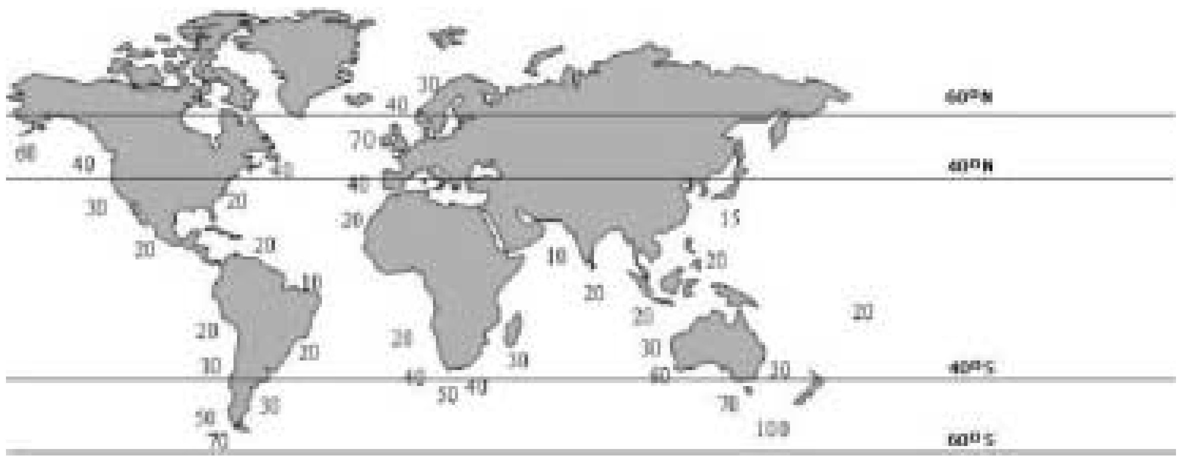

Figure 3. Global distribution of wave power levels (kW/m of crest length) (adapted from [29]).

The water is then either returned to the ocean through a turbine to produce electricity or is used to supply a reverse osmosis filter to produce fresh water. The need for costly submerged electric cabling and marine-based generation plant is thereby avoided.

A prototype CETO generator housed in a 20 metre steel hull in about 7 metres of water is situated at Fremantle, Western Australia (figure 5). The ability of the unit to pump water, expected to be at 7000 kPa, is being tested. In the desalination mode, the prototype is expected to produce 300,000 litres of fresh water per day. The next phase of the CETO project is the connection of the turbine’s ancillary equipment and a generator, which is expected to be 100 kW [34]. Seapower Pacific was acquired by the London-based Renewable Energy Holdings in 2006.

Figure 4. Energetech's 300 kW wave generator at Port Kembla, NSW (source: Energetech).

Figure 5. Prototype CETO Wave Conversion generator, Fremantle, Western Australia source: Sea Power Pacific).

Overseas companies are also looking at investing in commercial wave energy projects in Australia in the near future. The parent company of one other Australian company, Ocean Power Technologies (Australasia) (OPTA), has completed extensive environmental assessments to demonstrate the feasibility of its PowerBuoy wave power generator for use at US Navy bases throughout the world (figure 6). Ocean Power Technologies (OPT) deployed its second generation PowerBuoy devices at a depth of 30 metres in June 2004 and October 2005 as part of an assessment of the potential to develop a 1 MW plant at the Marine Corps Base, Oahu, Hawaii. The New Jersey Board of Public Utilities has purchased another 40 kW PowerBuoy, which was deployed near Atlantic City, New Jersey in October 2005, at a depth of 18 metres. Development of a 1.25 MW plant for a Spanish customer, Iberdrola S.A. at Santoña, Spain, is expected to be operational in 2007. The company recently applied to construct a 50 MW wave energy project in Oregon. These trials and commercial projects will position OPTA to deploy OPT's PowerBuoy technology in Australia.

Other wave generation technologies that could be used in Australia include Ocean Power Delivery's (OPD's) Pelamis wave generator. OPD is currently testing a 750 kW generator on the Portuguese coast and, pending the outcomes of the trial, has a contract to construct a 2.25 MW unit. Another wave generator, WaveGen's Limpet, is a fixed-generating device and a grid-connected 500 kW unit has been operating in Scotland since 2000 [36]. The commercialization of these and other wave generation technologies will enable wave power to make an important contribution to Australia's future electricity generation mix.

Figure 6. OPT’s PowerBuoy wave generator (source: Ocean Power Technologies).

4. Conclusions

- Australia has very limited hydroelectric power resources and these have mostly been fully developed.
- There is some potential to increase the hydro power contribution in Australia through pump-back schemes, improved turbine designs and small-scale facilities.
- Australia has an excellent tidal resource in the Kimberley region of north-west Australia, but this resource has not been developed so far because several feasibility studies have shown that it is not cost-effective, due to the lack of a local grid and the small demand for electric power in the local region.
- Australia has promising wave power resources along its western and south-western coasts and efforts are underway to develop technologies to exploit this resource. Several promising devices are currently being demonstrated to determine whether they would be cost-effective in favourable locations.

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